

# APPLICATIONS OF ACTIVE CONTROL

Kam W. Ng  
Office of Naval Research  
Arlington, Virginia

**Abstract** Active control of noise and vibration has received a great deal of attention in recent years. Accordingly, substantial progress has been made in understanding of the principle, development, and applications of active control technique. This presentation focuses on the acoustic and non-acoustic applications of active control technology. Specifically, implementations toward noise and vibration control, control of dynamical systems, and processes are presented. Research and development efforts in active/passive control are also discussed. Technical issues, such as broadband control, transient operation, complex structures and systems, and controller instability are addressed. Furthermore, recommendations and future research directions are discussed.

## 1. Introduction

Over the last decade there has been substantial amount of work done on reducing noise and vibration of structures and mechanical systems using active control. This accelerating interest, is reflected by the large number of conferences, publications, and patents on active control. Advances in adaptive materials, signal processing, and control approaches have enabled the realistic implementation of many active control techniques. As documented by many investigators, the active control techniques have been applied successfully to simple structures such as beam, plate, and cylindrical shell, as well as many simple mechanical systems.

This paper does not attempt to give an exhaustive review of the active control techniques. Rather, the purpose of the paper is to discuss some of the acoustic and non-acoustic applications and technical issues, and provides recommendations and future research directions.

## 2. Active Control Concept

Active sound cancellation or anti-sound concept was patented in 1936 by Lueg<sup>1</sup>. Essentially, the concept is based on the superposition principle that a sound signal is canceled by a second identical sound signal produced 180 degrees out of phase with the first one. As described by Lueg, a microphone detects the source of sound and converts it into an electrical signal which is fed to the amplifier. The loudspeaker, driven by the amplifier with time delay, produces the anti-phase signal which cancels the original sound. This active sound cancellation or active noise control concept has been implemented widely for one-dimensional duct noise problem, as well as three-dimensional problems found in enclosures, sound studios, and headphones. A more detailed discussion of the active noise control concept is documented by Nelson and Elliott<sup>2</sup>.

Wavenumber domain approaches for active control of sound have been investigated analytically and experimentally on simple structures by Fuller and many others. Specifically, the Active Structural Acoustic Control (ASAC) or modal control has been developed for the control of sound radiation. As illustrated in Figure 1, ASAC involves modal restructuring that reduces supersonic (propagating) wavenumber components while increases subsonic (nonpropagating) components. It is well known that only supersonic wavenumber components radiate to the far field, and thus wavenumber domain approach is an effective technique which control sound radiation. A comprehensive discussion of the active structural acoustic control can be found in Fuller et al<sup>3</sup>

Using the active control methodology, Active Vibration Control (AVC) techniques have been developed which can be applied to reduce structural vibration. In AVC, the objective is to minimize vibration rather than sound radiation.

It has been found that active control techniques work quite effectively on tonals in the 100 to 1000 Hz range. Initially, the active control techniques have been used for noise and vibration applications; and recently the active techniques are being extended to other non-acoustic applications.

### **3. Applications**

With advances of sensors, actuators, digital signal processors (DSP), and other electronic devices, the ability to develop "real time" practical active control systems has become a reality. In addition, there have been significant advances in the development and use of adaptive materials which have enabled the realistic implementation of many active control techniques. These materials include piezoceramics (PZT-5H), piezo film (PVDF), electrostrictor (PMN), magnetostrictor (TERFERNOL), shape memory alloy (NITINOL), shape memory ceramics (PLZST), piezo composites, fiber optics, electrorheological (ER) and magnetorheological (MR) fluids/materials, and micro-electro mechanical systems (MEMS).

#### **3.1 Acoustic Applications**

For discussion purpose, the acoustic applications are divided into: 1) Matured Technology, 2) Technology under Development, and 3) Active/Passive Control.

##### **Matured Technology**

The most practical and frequent active noise control implementations are one-dimensional duct noise propagation problem for airborne noise control. Active control technique has been used as intake or discharge silencers for heating, ventilation, and air conditioning (HVAC) systems, and related equipment such as fans, blowers, and compressors. Also, headphones have been developed which utilize the active cancellation technique to reduce background noise so that pilot in a noisy environment can communicate with air traffic controller.

Accordingly, active control systems and devices for duct noise and headphones for communication are matured and commercially available.

##### **Technology under Development**

Predominantly, active control techniques were developed for noise and vibration control. To-date, most of the active control techniques are still under development. Examples of the active noise and vibration applications include aircraft cabin noise, aircraft gas turbine engine noise, diesel and combustion engines, automobile engines and tire noise, and electrical transformer noise; as well as audio control for studios, and noise control for smaller mechanical components, i.e., fans, motors, blowers, mufflers, and appliances, such as refrigerators.

Other specific examples are as follows:

Machinery raft isolation using active control technique has been demonstrated by Swinbanks et al<sup>4</sup>. The structural dynamics of a raft with passive and reciprocal characteristics is modified by active control to have non-reciprocal behavior. The seaway motion in the machinery raft base is distinguished and separated from noise vibration on topside raft in the opposite direction. Uniquely, the signal processing power of the controller, 3.6 G-Flops DSP, allows 4 separate control algorithms: stable lift, seaway control, modal control, and high frequency modal, to operate simultaneously. The demonstration has shown the capability to selectively isolate raft resonant modes and control independently the force pattern output at the base. Capabilities are being extended to larger raft with 32 tri-axial actuators, as shown in Figure 2, with fully three-dimensional flexible structure and to support realistic equipment with complex vibrations. This technology provides the opportunity to construct large, lightweight platforms which can provide high levels of isolation for any machinery mounted on them. Furthermore, it allows more relaxed vibration specifications to be applied to machinery, with subsequent reduction in cost.

Electro-Active Elastomeric Structures (EAES) concept as shown in Figure 3 employs an electro-active elastomer formed by the incorporation of an electrorheological (ER) fluid within the pore structure of a silicone elastomer<sup>5</sup>. Materials formed in this manner exhibit the classical ER effect, i.e., rapid, reversible changes in properties as a function of applied electric field. A structure comprised of a layer of electro-active elastomer covered with a layer of conductive elastomer forms an adaptive material capable of responding to a spatial time-dependent voltage stimulus. The inclusion of sensors and feedback loop completes the EAES concept. This EAES concept is being investigated for flow noise and acoustic absorption applications.

Aerodynamic noise due to rotor wake/stator interaction has been reduced using active control technique on a simple system consisting of a two bladed rotor and a single vane has been demonstrated by Simonich et al<sup>6</sup>. A servo actuated trailing edge flap vane has been used to counter the unsteady lift created by an incident gust, thereby reducing the unsteady surface pressure and hence interaction noise.

### Active/Passive Control

There are two general types of active/passive noise control approaches: the adaptive-passive techniques and active-passive hybrid techniques. The adaptive-passive techniques are essentially passive devices with adaptations or changes that optimize performance. Active-passive hybrids use both active and passive elements in either series or parallel. The passive device usually carries the primary control function, while the active component is used to enhance the passive system or overcome the limitations of the passive system.

An example of the adaptive-passive techniques is the Actively-controlled Constrained Layer Damping (ACLD) treatment, which has been used to damp out the vibrations of flexible structures<sup>7</sup>. The ACLD as shown in Figure 4 consists of a visco-elastic damping layer which is sandwiched between two piezoelectric layers. The three-layer composite when bonded to a vibrating surface acts as ACLD treatment with built-in sensing and actuation capabilities. The sensing is provided by the piezo film directly bonded to the vibrating surface whereas the actuation is generated by the other piezo film which acts as an active constraining layer.

Other examples of the adaptive-passive techniques are the adaptive tuned absorber concept developed by von Flotow et al.<sup>8</sup> and real-time adaptable circuits by Wang et al<sup>9</sup>. von Flotow's adaptive absorber uses a stepper motor to continually adapt the load to enhance the dynamic effect of the absorber; and the absorber is utilized to control structural vibration and sound radiation from turbo-prop aircraft. Wang uses piezoelectric materials with real-time adaptable electrical networks to control structural vibration. With an adjustable circuit, a variable resistance and the changing rate of a variable inductance are used as control inputs.

An example of the active-passive hybrid technique is the active foam concept developed by Fuller et al<sup>10</sup>. The active foam concept and design originates from the combination of the active and passive control strategies that can efficiently operate over a broad range of frequencies.

### 3.2 Non-Acoustic Applications

Recently, active control techniques are being applied to other non-acoustic applications. Non-traditional applications include control of aircraft wing, helicopter blade, turbomachinery, precision machining and fabrication, combustion, and turbulence; as well as used for control of nonlinear processes, machinery monitoring and diagnostics, and signal processing. In turbomachinery, active control techniques have been used to suppress rotating stall in axial compressor and pressure surge in combustor. Active control of nonlinear processes include control chaotic oscillations related to air and undersea vehicles, shipboard crane operation, power electronics distribution and generation, and lasers.

Some of the other specific examples are:

Active control techniques are combined with advanced materials to develop adaptive wing design to improve performance of aircraft<sup>11</sup>. The adaptive wing design as shown in Figure 5 has the following features: 1) wing twist using shape memory alloy (SMA) actuators to enhance lift in multiple flight regimes, 2) leading edge (LE) and trailing edge (TE) control surfaces using SMA and piezoelectric composite actuators to achieve minimum drag and maximum lift, 3) surface coated with polymer material to actively reduce drag and noise generated by turbulence, and 4) embedded fiber-optic sensor arrays for real-time aerodynamic pressure measurements.

Similarly, Jacot et al.<sup>12</sup> utilize adaptive materials/structures and active control techniques to develop new blade design for helicopters. The new blade uses active composites, discrete and integrated sensors/actuators concepts to improve aerodynamic performance, while reduces structural vibration and sound radiation.

Active surface concept has been applied to control and diagnose turbulence in a boundary layer using silicon microfabrication technology<sup>13</sup>. Electromagnetic control of turbulence, and selective suction and injection are being used to control the turbulence of high Reynolds number flows.

#### 4. Issues

Some of the technical issues or technological challenges are control of random noise and stochastic processes, broadband control, and control of transients. Active control of random noise and stochastic processes is a particularly difficult problem due to the general unpredictability of the response of interest. Recently, broadband control has received more attention but the capabilities are still limited. A possible solution for broadband control is to utilize multi-inputs and multi-outputs (MIMO) feedforward control with multi-rate controller. Transient control is possible using state space methods and radiation filters, but implementation is complex<sup>14</sup>.

Other specific issues that remain to be resolved include: 1) development of near-field structural sensors for active noise control of complex structures, 2) development of efficient numerical design procedures for active system with broadband disturbances, and 3) development of low order hierarchical controllers for active control of complex systems. Studies are required on the robustness and performance trade-off of realistic active control systems. In particular, control algorithms for fault identification and isolation are needed. Fault tolerant behavior and automatic protection features should be incorporated to make the integrated system highly robust to parametric uncertainties and disturbances.

A major technical challenge or research opportunity is nonlinear active control of dynamical systems. Areas of interest include control of nonlinear processes and dynamics in complex structures and systems, electro-mechanical systems, precision machining and fabrication, and both high and low-level controls of air and undersea vehicles. Specifically, the vehicles must be equipped with intelligent controller to successfully accomplish their missions (high-level control) in various environments. Because of complex fluid-structure interactions and inherently stochastic environment, vehicles must also be able to control the nonlinear dynamics (low-level control) due to stochastic disturbances.

#### 5. Recommendations and Future Directions

Active control is an enabling technology for a wide spectrum of applications. The strengths and weaknesses of active control techniques should be critically evaluated and the active control methodology should be harnessed for all potential applications.

*Performance, cost, and complexity* will remain the requirements and criteria of quantifying success for future active control systems. Accordingly, the active control techniques should be investigated and exploited continuously with

special attention on performance, cost, and complexity. Active control techniques and passive control techniques must be combined to form a cost effective and robust control strategy.

There is a need to coalesce the various *non-traditional* control applications into a *generic* problem and to develop a unified control methodology. In addition, the nonlinear control problems, such as high and low-level controls for air and undersea vehicles, nonlinear oscillations, and control of large-scale power electronics systems, should be investigated.

## References

1. Lueg, P., 1936, *Process of Silencing Sound Oscillations*, U.S. Patent 2,043,416.
2. Nelson, P. A. and Elliott, S. J., 1993, *Active Control of Sound*, Academic Press, London.
3. Fuller, C. R., Elliott, S. J. and Nelson, P. A., 1995, *Active Control of Vibration*, Academic Press, London (in-press).
4. Swinbanks, M. A., 1994, private communication.
5. Harder, C. R. et al., 1995, Electroactive Elastomeric Structure (EAES) for Hydroacoustic Applications, *Proceedings of ACTIVE 95*, Newport Beach, California, USA.
6. Simonich, J. et al., 1992, Active Aerodynamic Control of Wake-Airfoil Interaction Noise - Experiment, *DGLR/AIAA 14th Aeroacoustic Conference*, Aachen, Germany.
7. Baz, A., 1993, Active Constrained Layer Damping, *DAMPING '93 Conference*, San Francisco, California, USA.
8. von Flotow, A., 1994, private communication.
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10. Fuller, C. R. et al., 1994, Control of Sound Radiation/Reflection with Adaptive Foams, *Proceedings of NOISE-CON 94*, Ft. Lauderdale, Florida, USA.
11. Kuda, J. and Austin, F., 1994, private communication.
12. Jacot, D., 1995, Smart Structures for Rotorcraft Control, *Proceedings of ACTIVE 95*, Newport Beach, California, USA.
13. Bandyopadhyay, P. R., 1995, Microfabricated Silicon Surfaces for Turbulence Diagnostics and Control, *Proceedings of ACTIVE 95*, Newport Beach, California, USA.
14. Fuller, C. R., 1995, private communication.



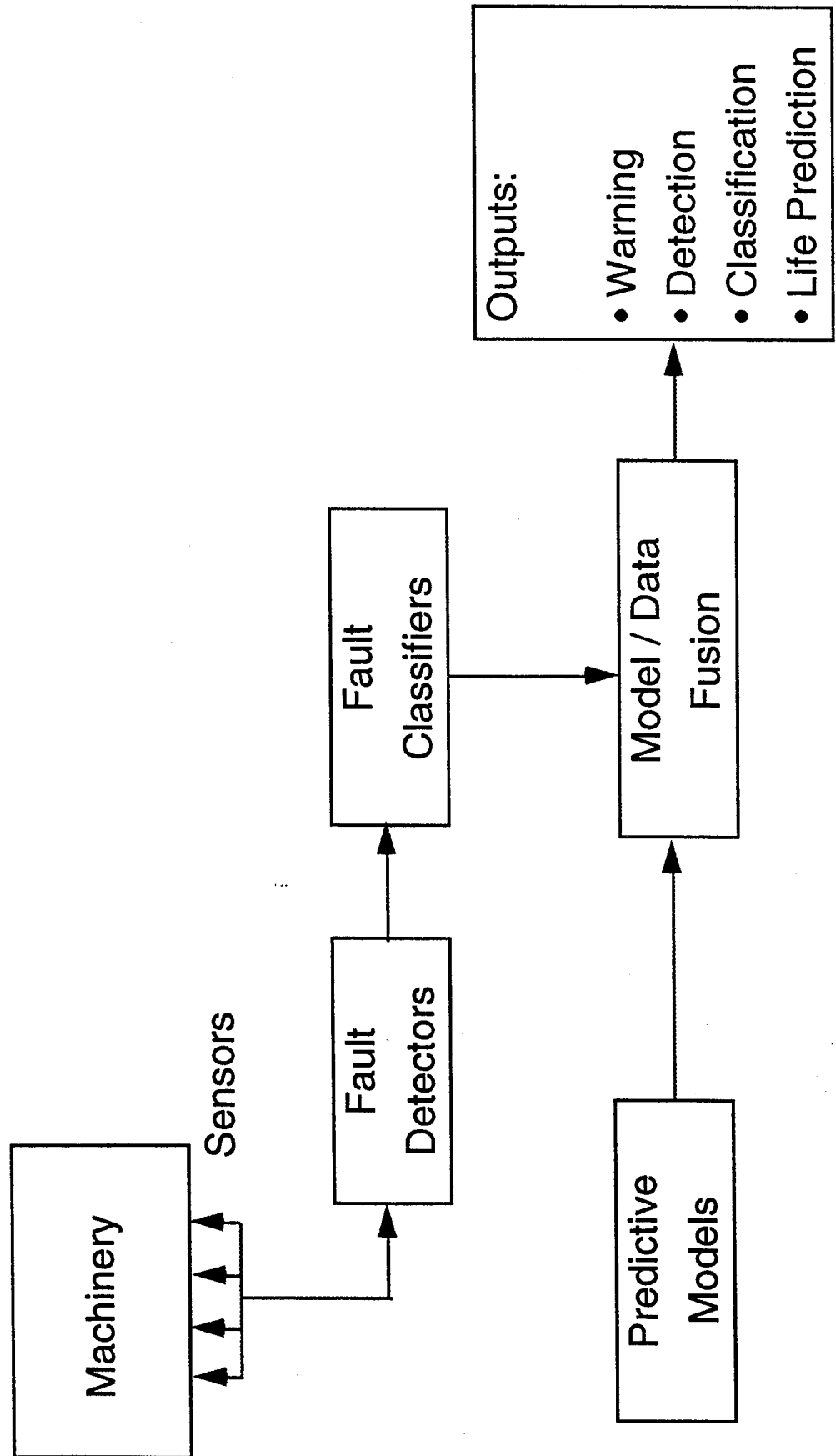
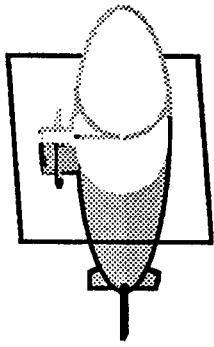
# OUTLINE

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- Introduction & Background
- Maintenance Concepts
- Fault Diagnostics & Prognostics
- Applications of Active Control
- Future Research Directions

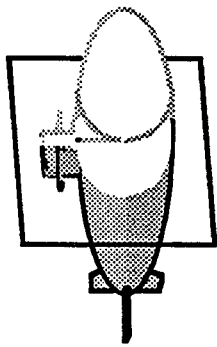


## KEY ELEMENTS OF CONDITION BASED MAINTENANCE SYSTEMS





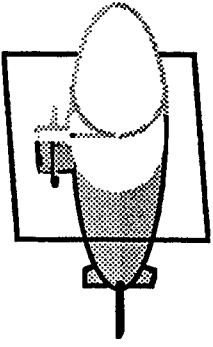
## REQUIREMENTS



- Safety
- Reduce maintenance cost & time
- Improve performance & effectiveness
- Reliability



## TIME VS CONDITIONED BASED MAINTENANCE



### Time Based Maintenance (TBM)

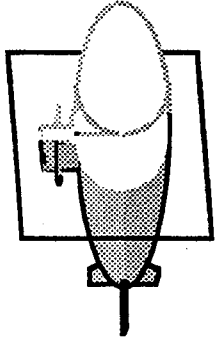
- Based on Rigid Overhaul Schedule
- Unnecessary Maintenance
- Costly
- Ineffective

### Condition Based Maintenance (CBM)

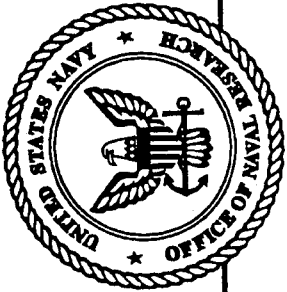
- Based on Condition
- Predictive Capability
- Preventive Maintenance



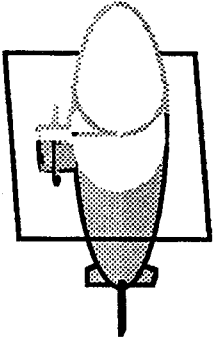
## TECHNICAL ISSUES



- Data Base
- Identification of dominant modes of failures
- Sensing techniques and sensors location
- Extraction of features from noisy environment
- Model / Data fusion
- Failure model for predicting time to failure
- Errors & uncertainties in detection/classification lead to **False Alarm**



## OPPORTUNITIES

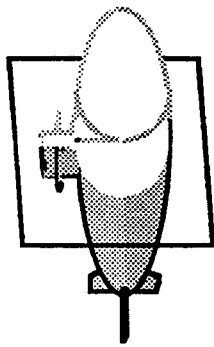


### EMERGING RESEARCH

- Fiber Optic & Noncontact Vibration Sensors - Laser Doppler Vibrometer
- Time-frequency Representations - Generalized Time-frequency Representation, Wavelet Transform
- Higher Order Spectra & Nonlinear Dynamic Models
- Neural Network
- Life Prediction Modeling - fatigue, creep & corrosion

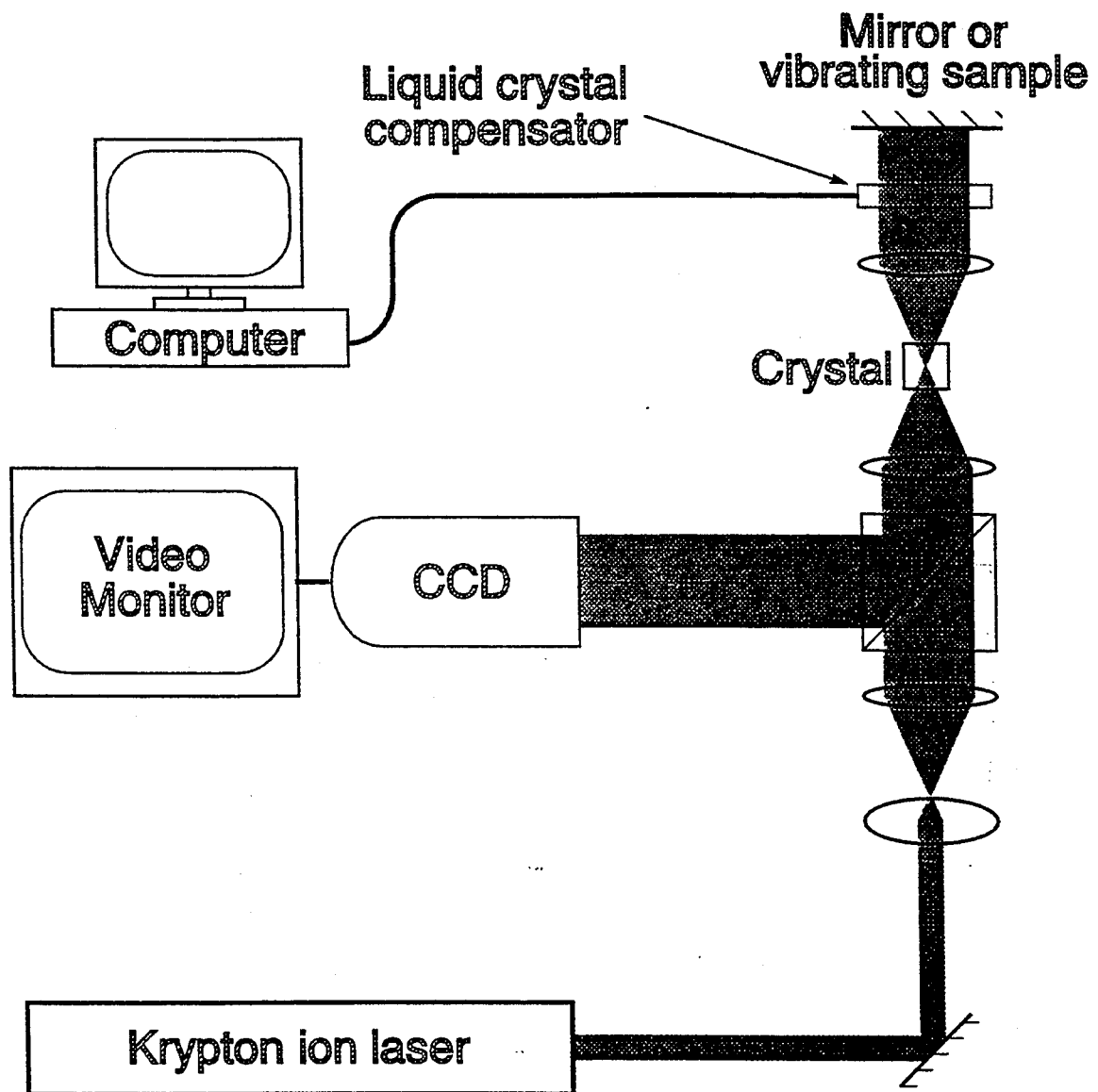


## SENSING & SENSOR



### PASSIVE and ACTIVE Techniques

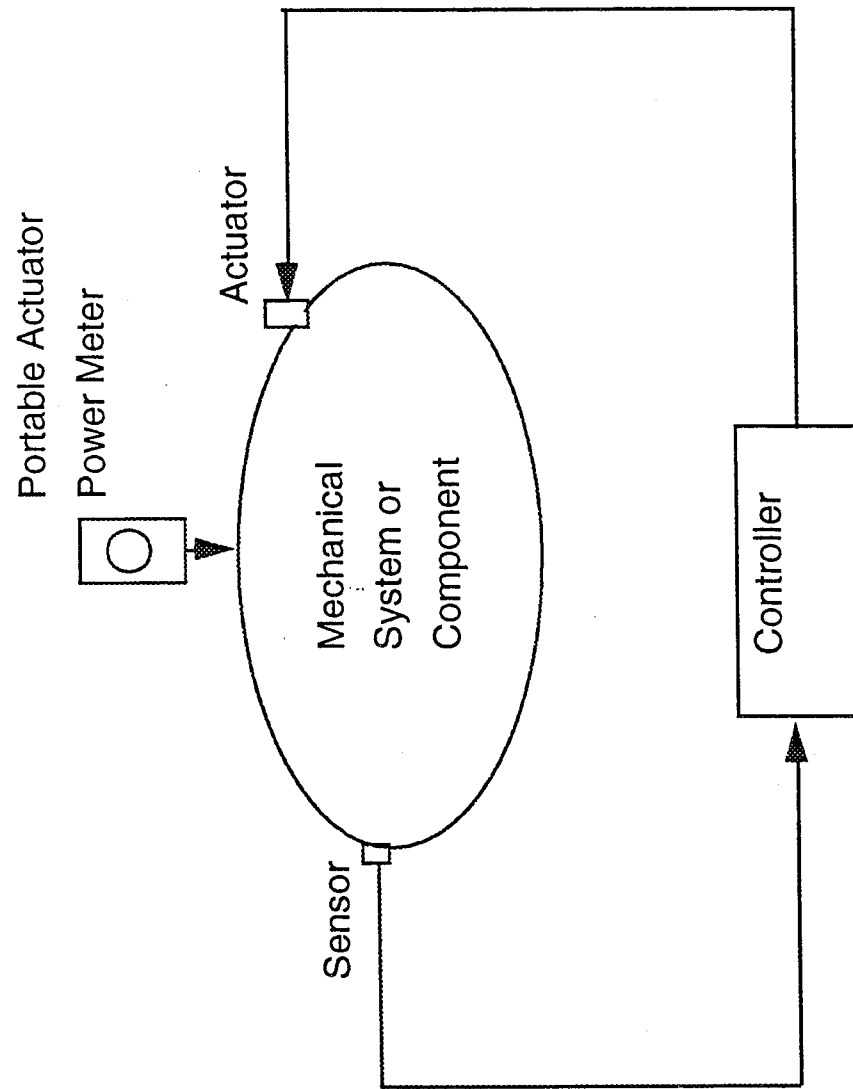
- Vibration & Velocity
- Displacement & Strain
- Pressure & Sound
- Flow
- Temperature
- Electrical Current, Resistance & Capacitance
- Miscellaneous
  - Force, Torque, Wear, Stress Waves, Leakage, Defect

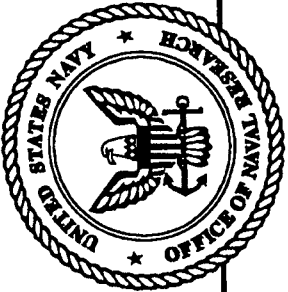


## Holographic Stress Analyzer

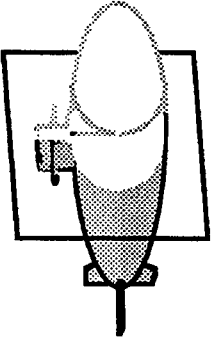


# ACTIVE CONTROL APPROACH FOR FAULT DETECTION & CLASSIFICATION





## **SIGNAL PROCESSING & FEATURE EXTRACTION / CLASSIFICATION**



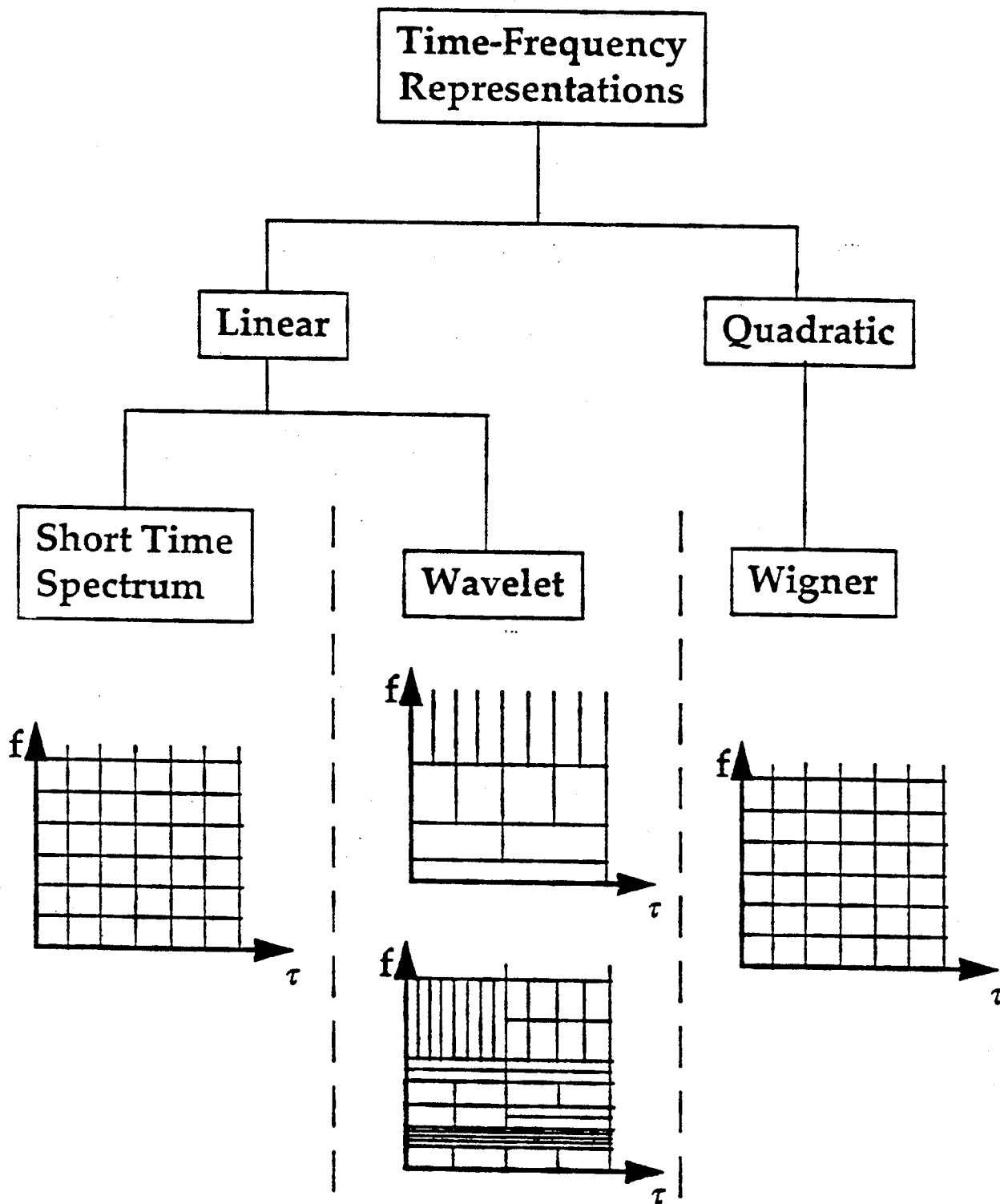
### **Signal Processing & Detection**

- Time Series & Statistical Analysis
- Time & Spatial Correlations
- Time-Frequency Analysis
- Cepstral Analysis
- Nonlinear Dynamic
- Higher and Lower Order Spectral Analysis

### **Classification**

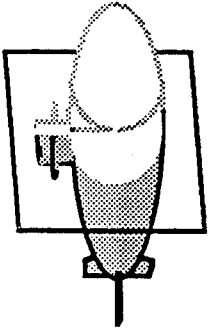
- Artificial Neural Network (ANN)
- Fuzzy Logic

# Time-Frequency Representations





## GENERALIZED TIME-FREQUENCY REPRESENTATIONS (GTFR)



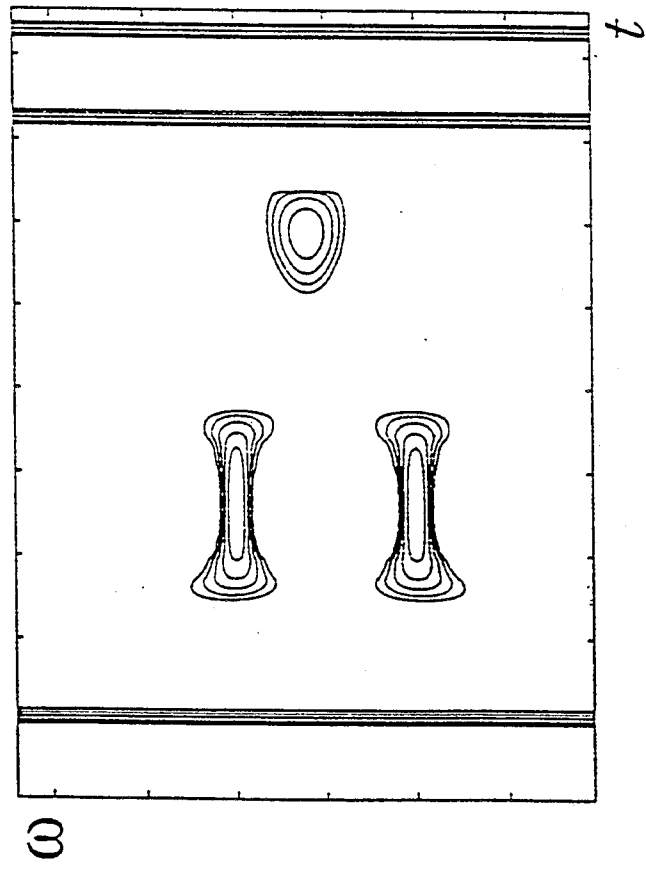
BASED ON WIGNER DISTRIBUTION

$$WD(t, \omega) = \int_{-\infty}^{\infty} e^{-j\omega\tau} f(t + \tau/2) f^*(t - \tau/2) d\tau$$

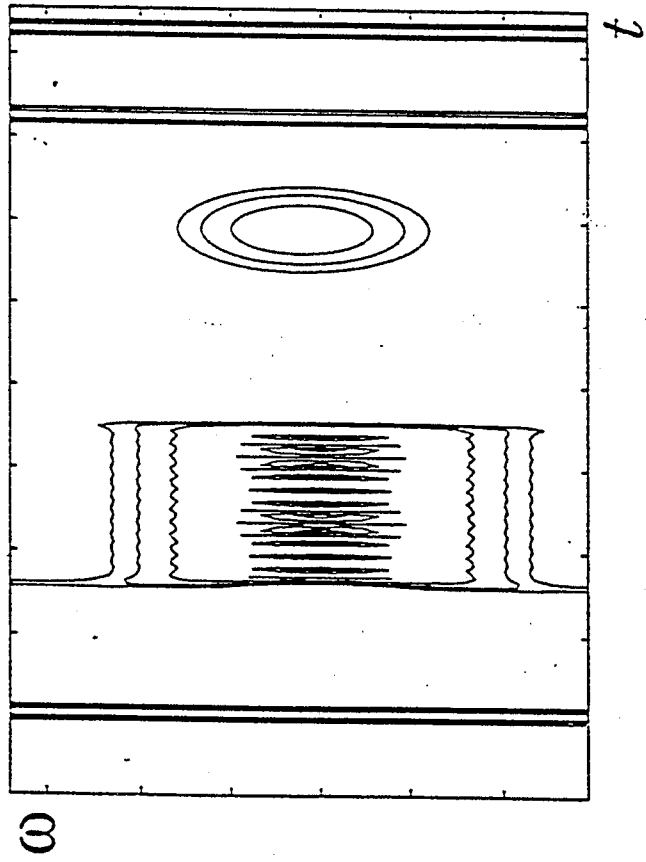
### ISSUES

- INTERFERENCE TERMS
- LACK OF DILATION & CONTRACTION CAPABILITIES
- ENERGY NOT CONSERVED

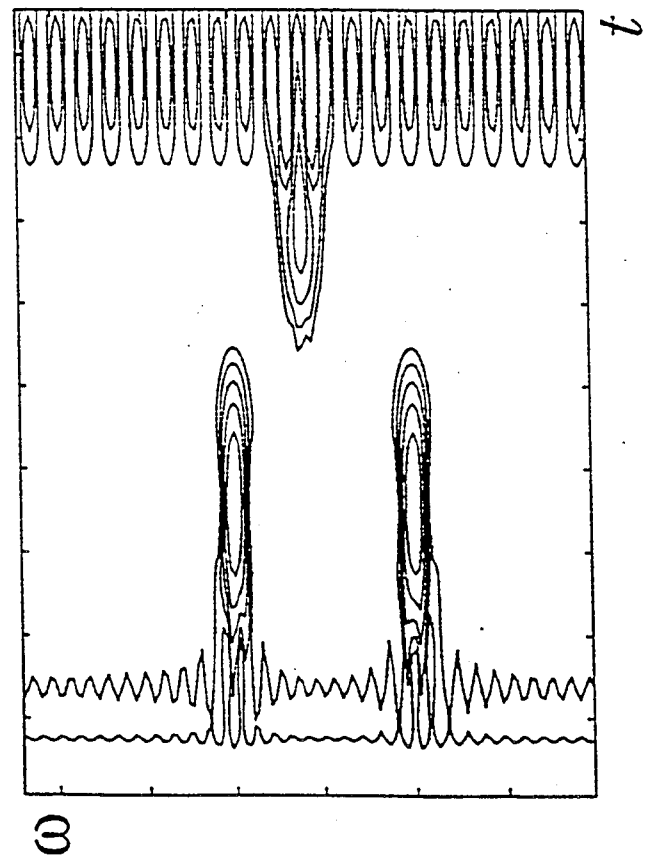
Signal Sample



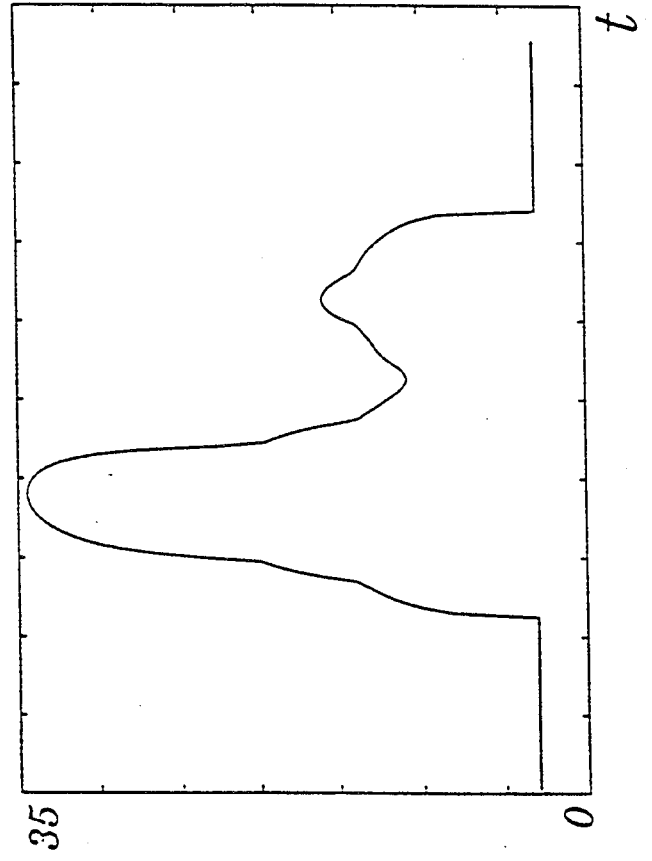
Short Time Window



Long Time Window

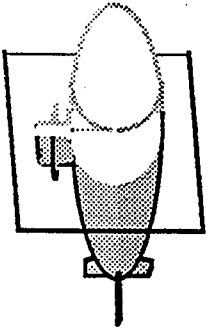


Adaptive Time Window





# WAVELET TRANSFORM

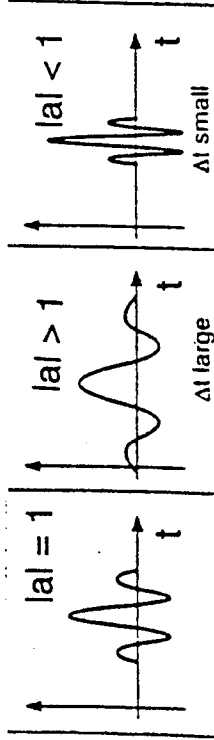


$$WT(t, \omega) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(\tau) \psi\left(\frac{\tau - t}{a}\right) \frac{d\tau}{a}$$

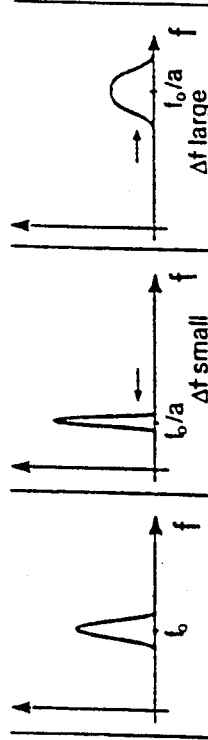
$a$  = scale parameter

$\psi$  = basic wavelet

Basic Wavelet      Dilated      Contracted



Time Series



Spectra

- WAVELET TRANSFORM PROVIDES ANALYSIS WITH CONSTANT PERCENTAGE BANDWIDTH

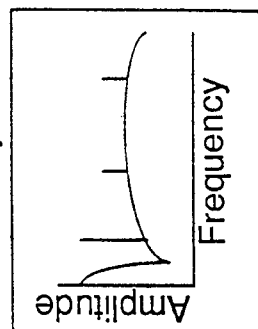
## ISSUES

- OPTIMIZED WAVELET FUNCTION



# HIGHER ORDER SPECTRA CONCEPT

Power Spectrum:



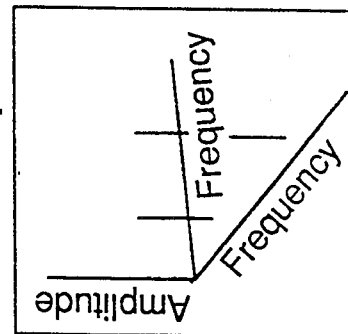
—frequency intensity

Magnitude

$$|X(\omega)|^2$$

— magnitude only

Higher Order Spectrum:



—frequency interactions

Cumulant

$$[X(\omega_1), X(\omega_2), \dots, X(\omega_n)]_n$$

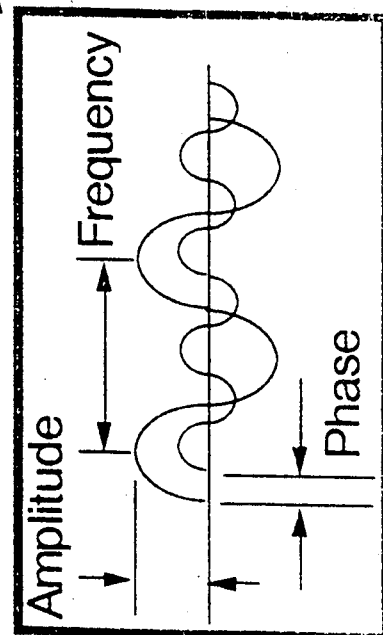
— magnitude and phase

( =0 if all components are independent )

FFT  
(magnitude and phase)

$X(t)$

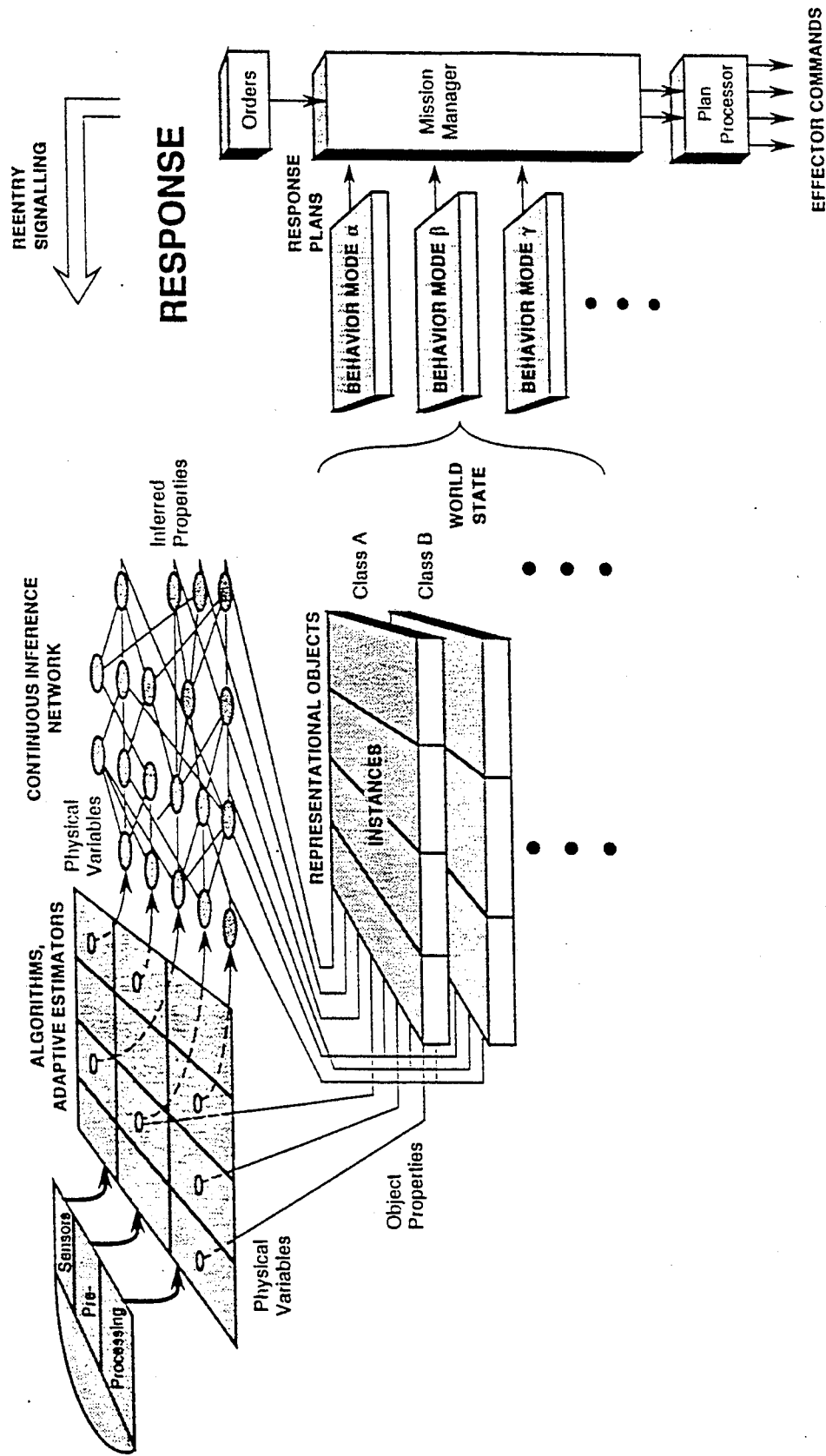
$X(\omega)$



UNCLASSIFIED

# PROTOTYPE INTELLIGENT CONTROLLER PROCESSING ARCHITECTURE

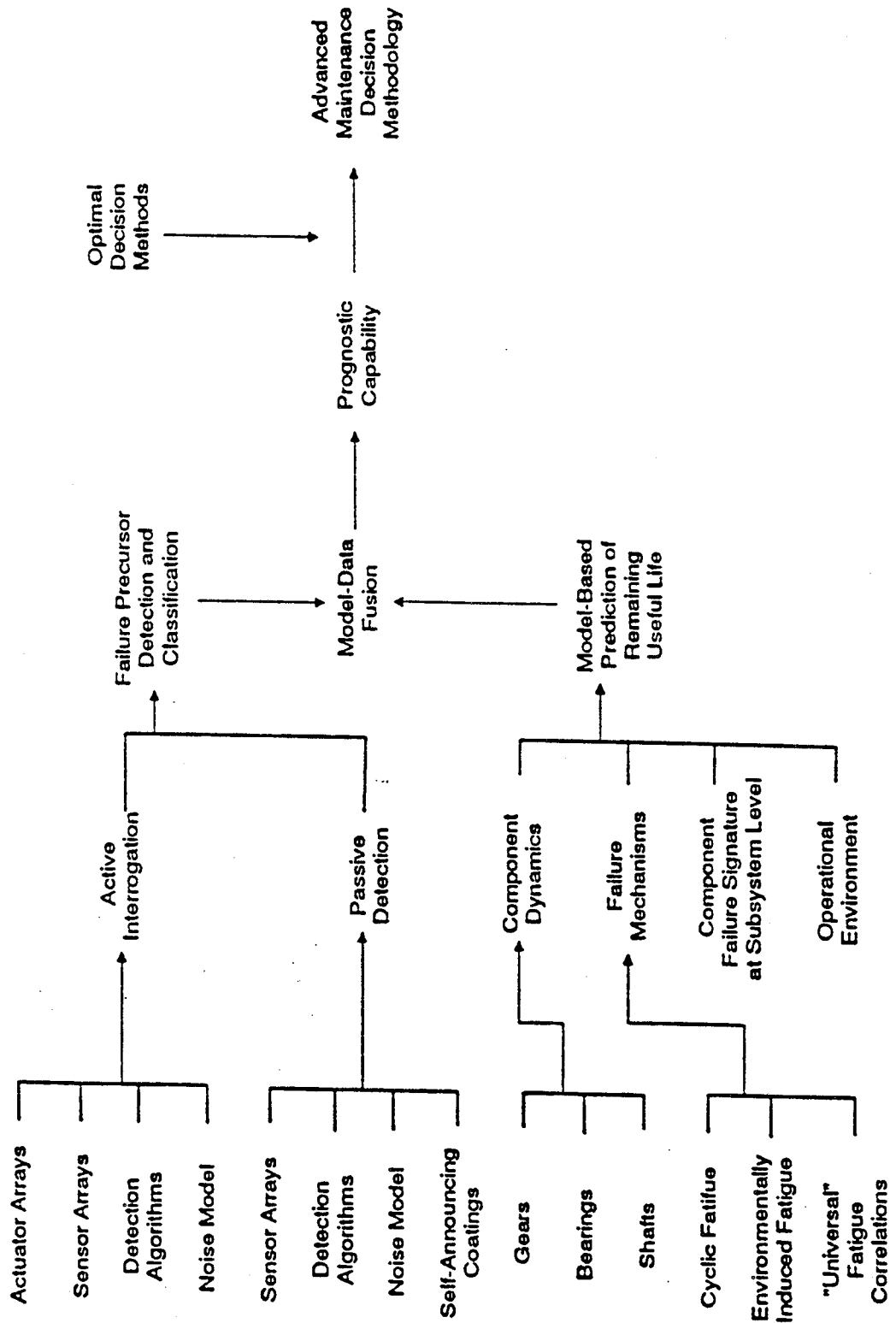
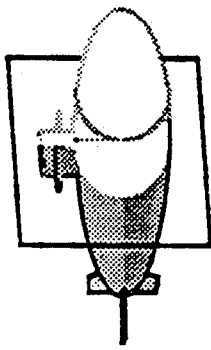
## PERCEPTION



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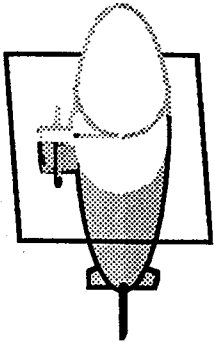


# MODEL - DATA FUSION





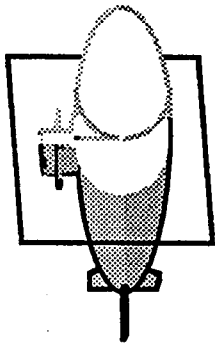
## APPLICATIONS OF CBM



- **Platforms** : Submarines, Ships, Land Vehicles, Aircraft, Rotorcraft
- **Systems & Subsystems** : Rotating Machinery, Engines
- **Components** : Gears, Bearings, Electrical
- **Elements** : Structural Elements - Beam, Plate & Shell,
- **Materials** : Metallic & Non-Metallic, Composites



## CONDITION BASED MAINTENANCE

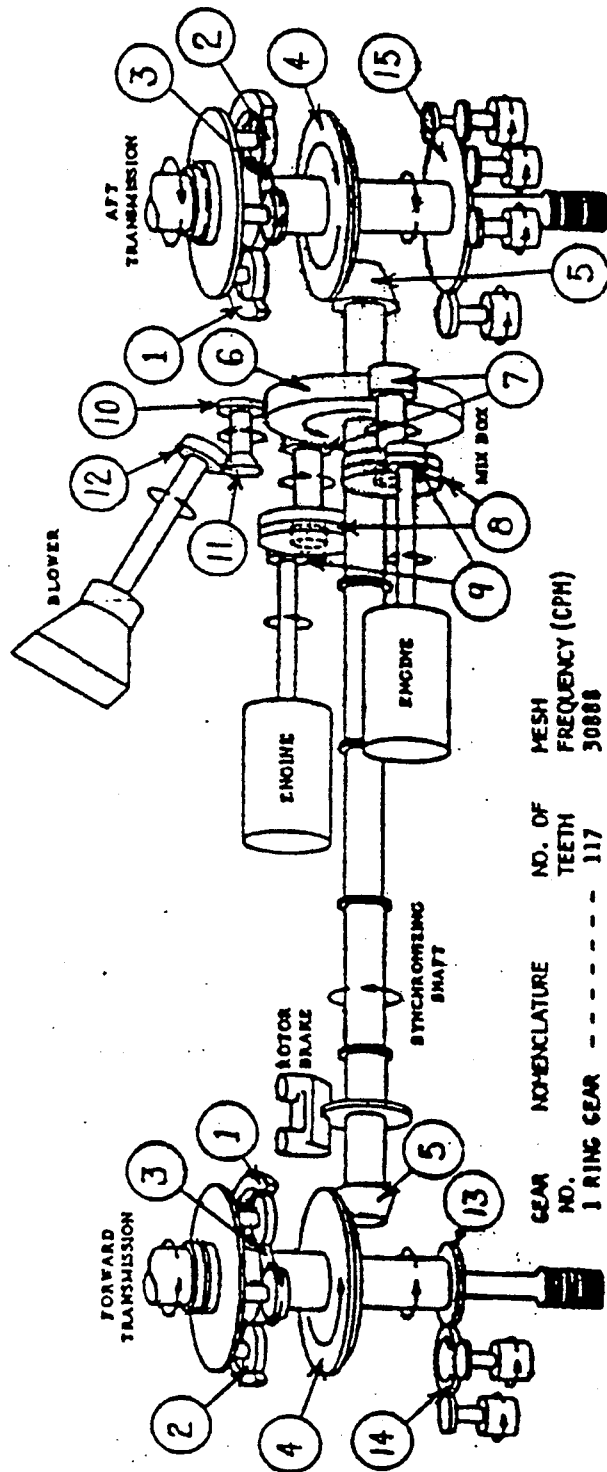


Results from

Helicopter Gear Box Data

- Detection
- Classification

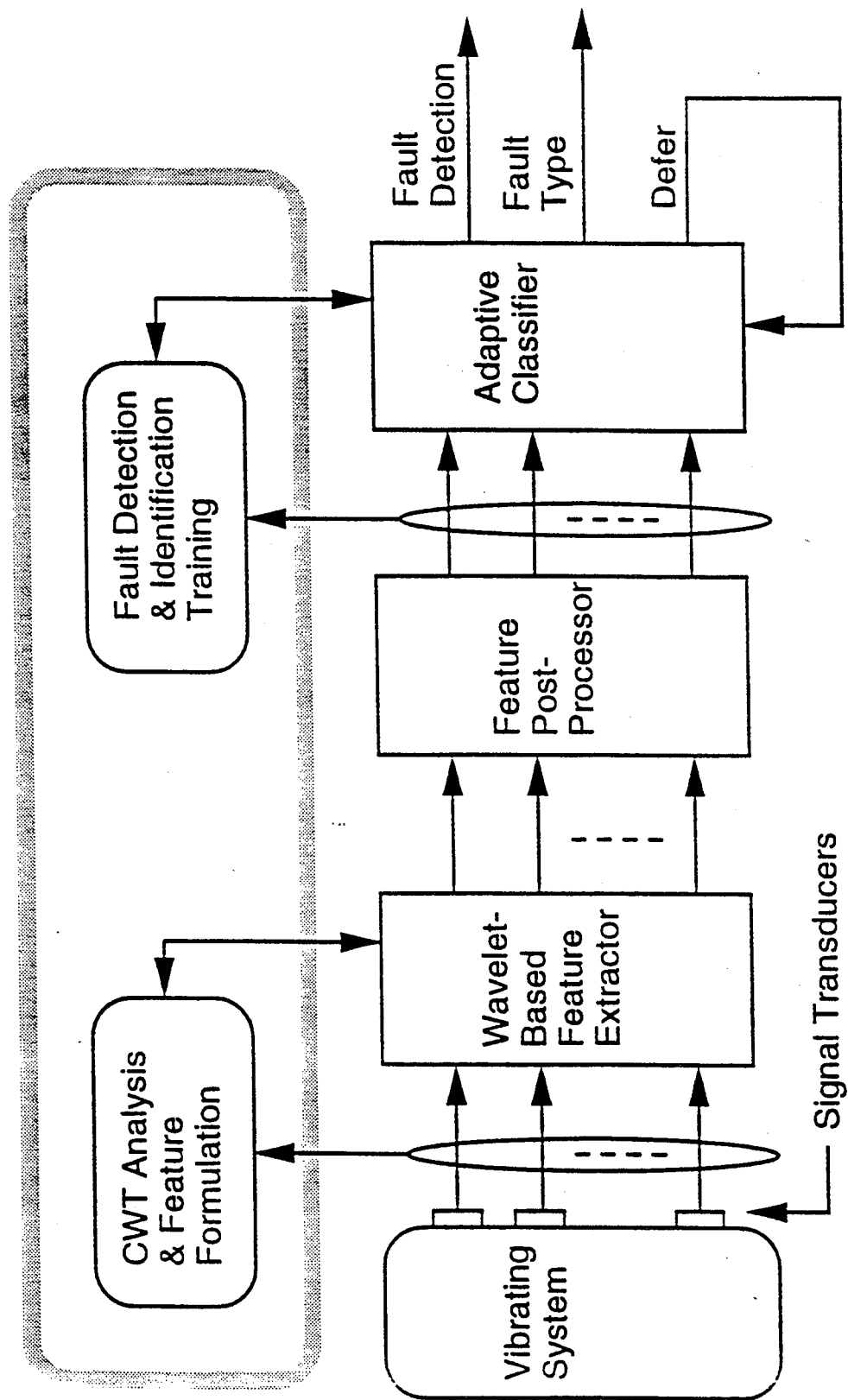
# H-46 Helicopter Gearbox

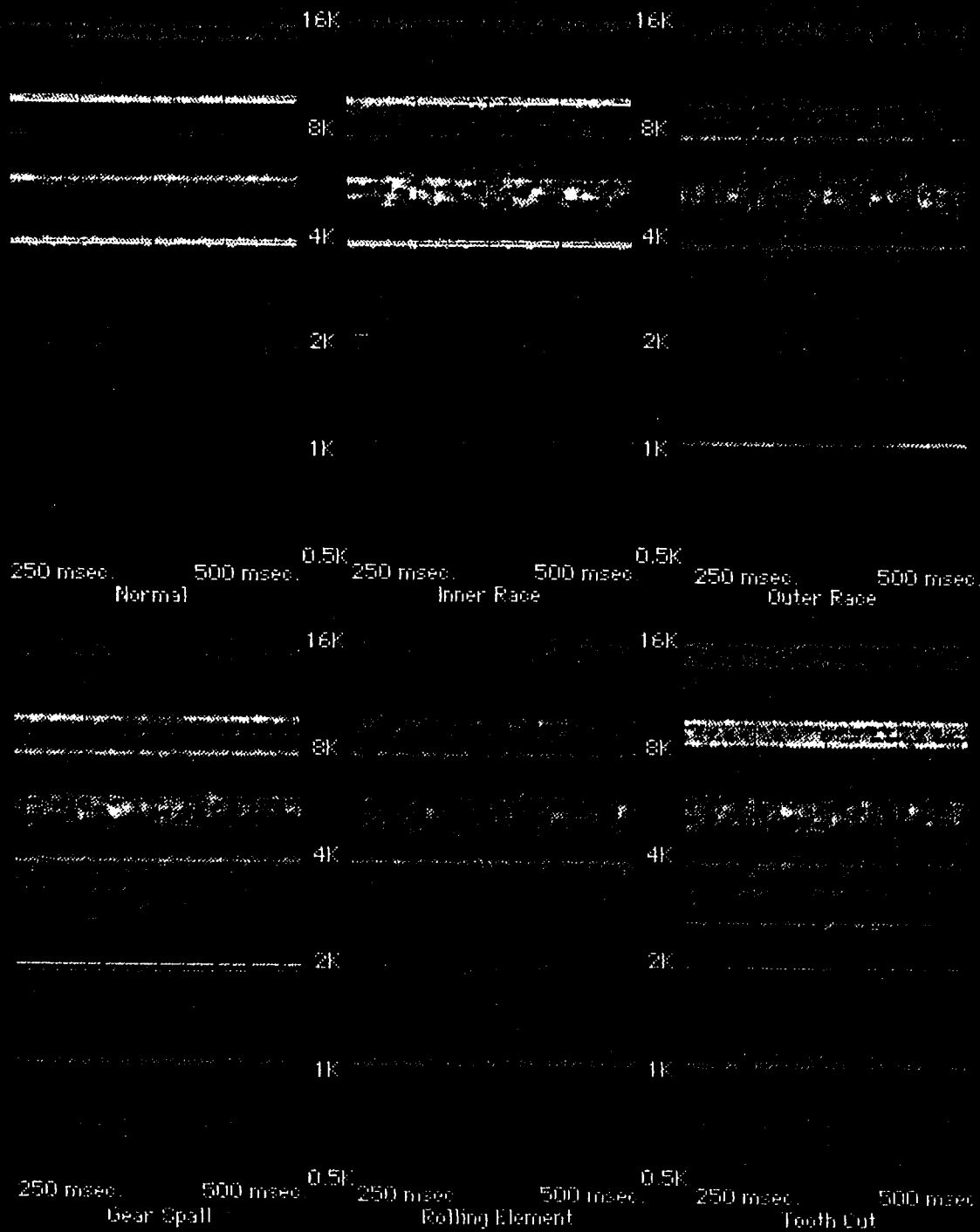


GEAR NO.	NOMENCLATURE	NO. OF TEETH	MESH FREQUENCY (CPH)
1	RING GEAR	117	30888
2	PLANET GEAR	39	30888
3	SUN GEAR	39	30888
4	SPIRAL BEVEL GEAR	63	66528
5	INPUT PINION GEAR	26	66528
6	COLLECTOR GEAR	74	189349
7	SPUR GEAR	25	189349
8	MIX BOX IDLER GEAR	72	545328
9	MIX BOX PINION GEAR	28	545328
10	BLOWER SPUR GEAR	25	189349
11	BLOWER BEVEL GEAR	25	189349
12	BLOWER PINION GEAR	31	189349
13	AUXILIARY DRIVE SPUR GEAR	86	90816
14	AUXILIARY IDLER GEAR	90	90816
15	AUXILIARY DRIVE SPUR GEAR	130	137280

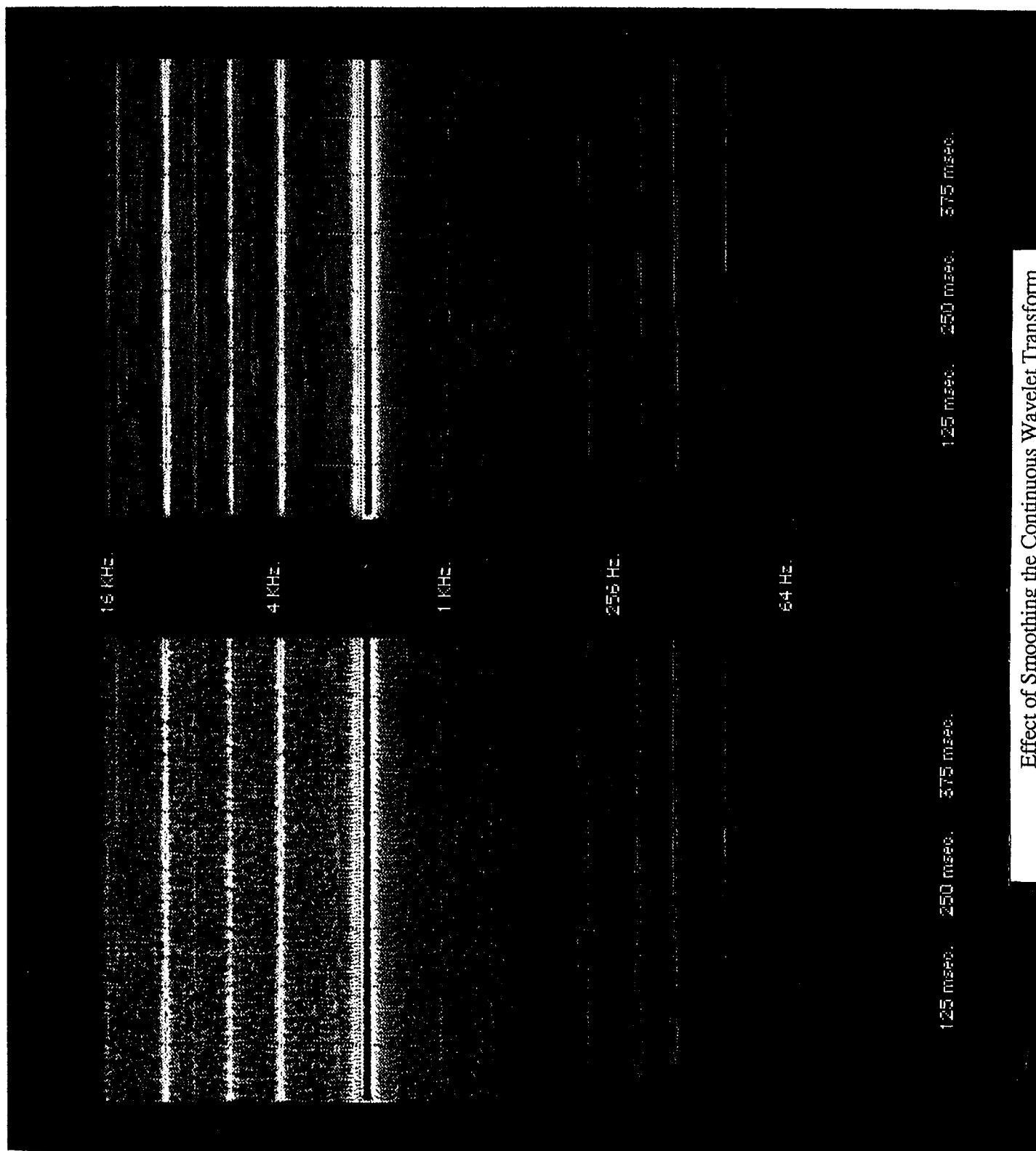


# WAVELET-BASED APPROACH TO FAULT DETECTION





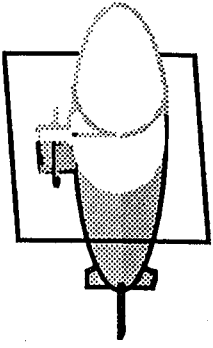
Helicopter Gearbox Signatures After Masking Out Low-Level Energy



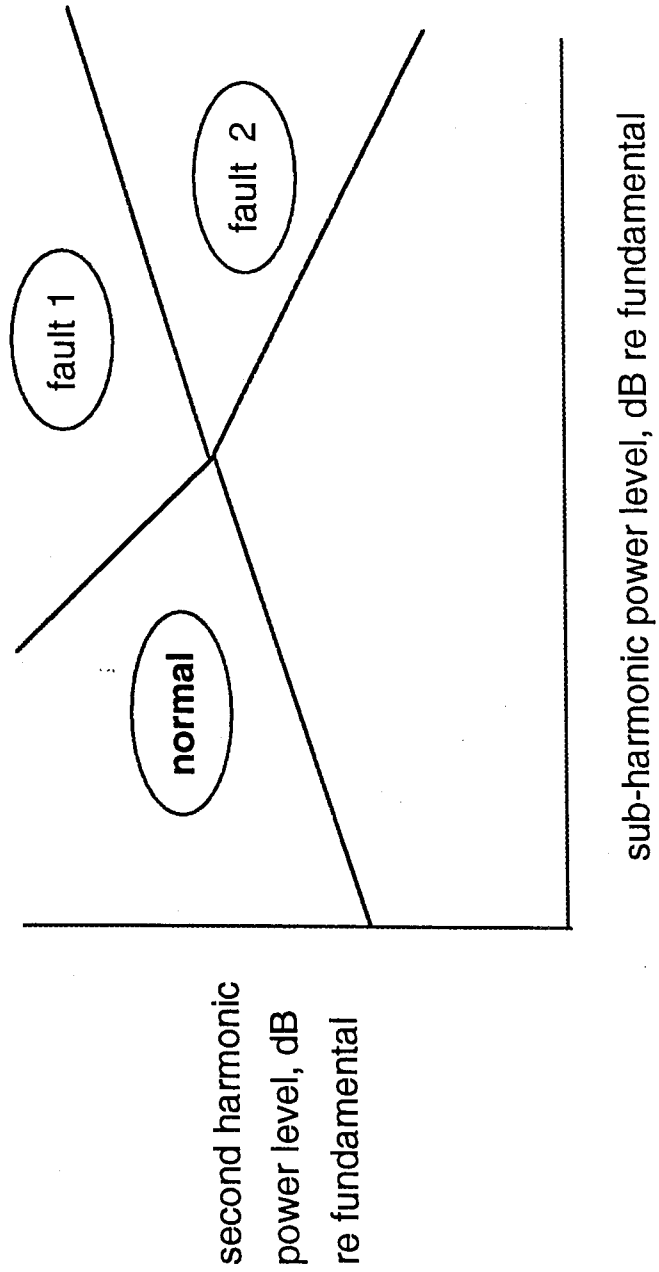
Effect of Smoothing the Continuous Wavelet Transform

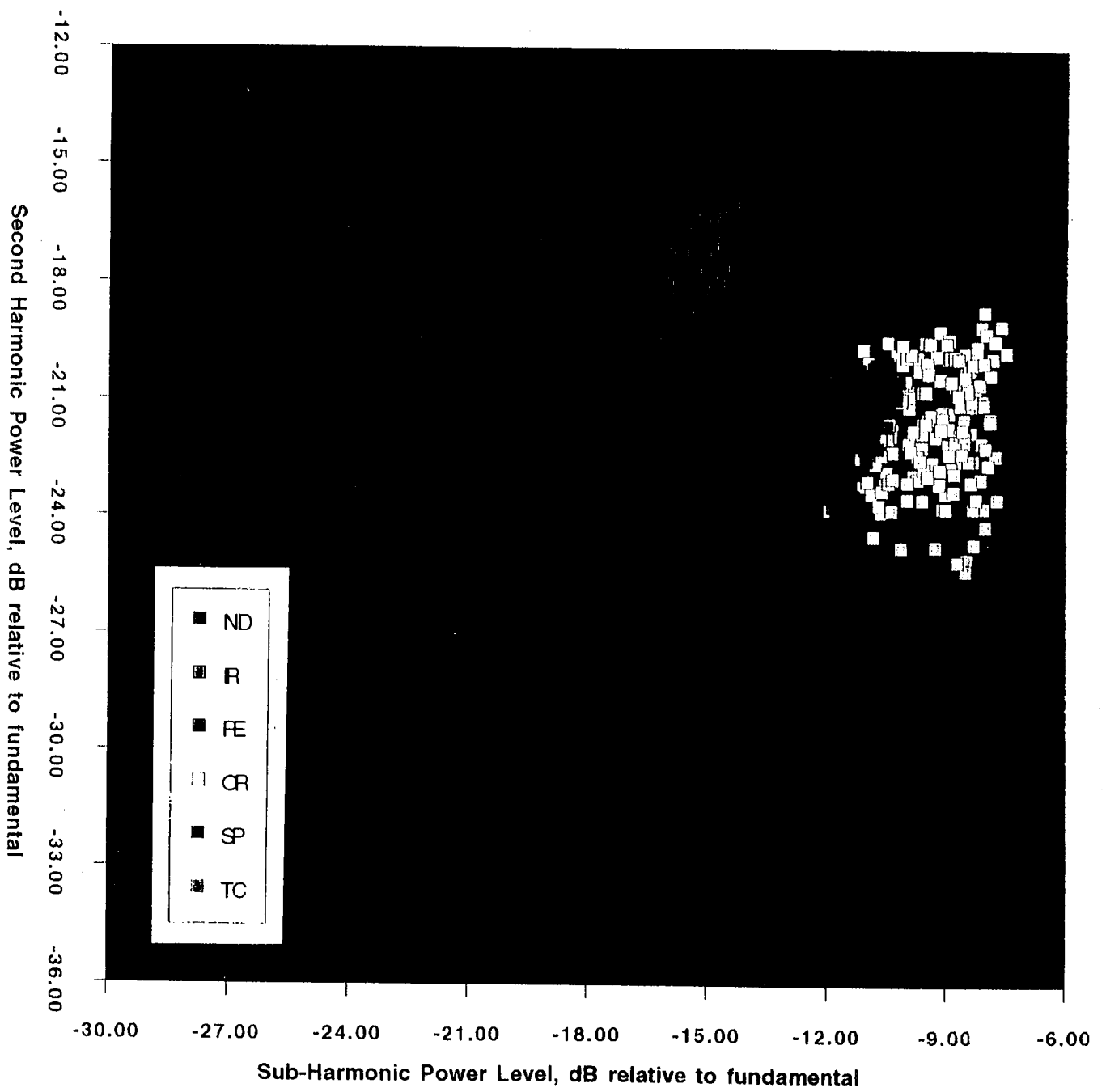


## FEATURES EXTRACTION



- Clusters of features separation  
e.g. correlating second harmonic power level with sub-harmonic power level





Fault Features Cluster Separation



# ACTIVE CONTROL

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## Components of Rotating Machinery

- Fan Blade
- Rotor
- Compressor
- Turbine

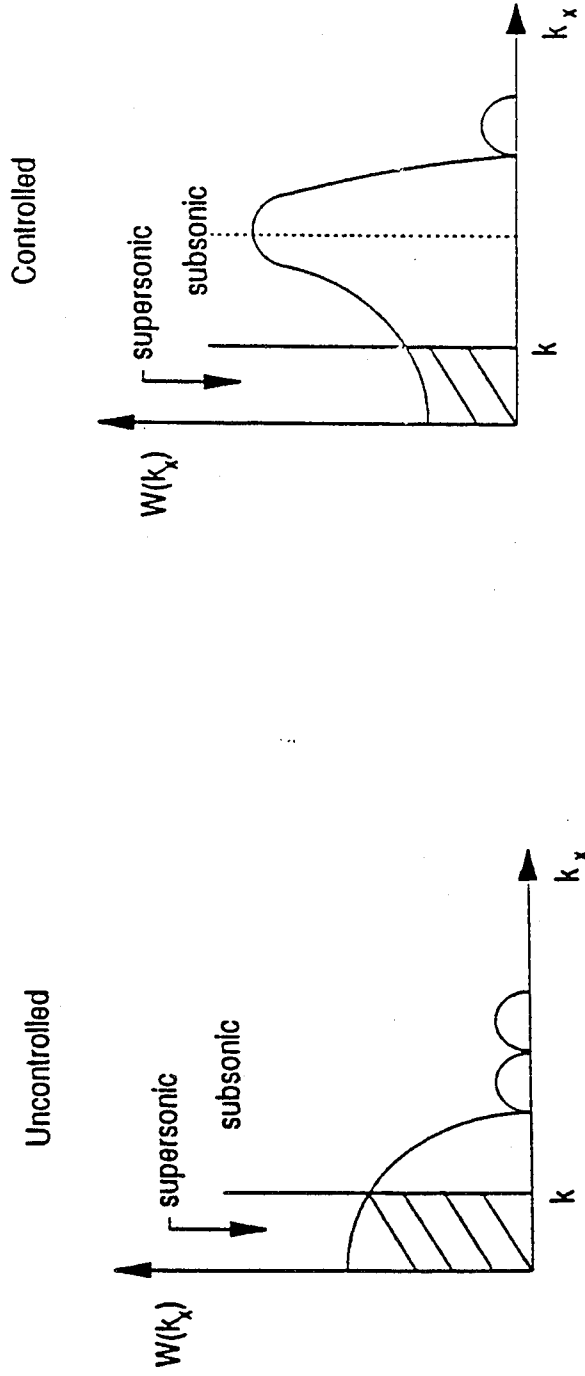
## Applications

- Compressor Stall & Surge
- Flutter
- Aerodynamic Control
- Balancing
- Noise & Vibration



## ACTIVE STRUCTURAL ACOUSTIC CONTROL

### Plate with and without Active Control



- Modal Restructuring  
Energy shift from **Supersonic** component to **Subsonic** component

Source: Fuller, VPI



## ADVANCES FOR ACTIVE CONTROL

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- **Digital Signal Processors (DSP)**
- Related Electronic Devices
- **Adaptive Materials**
  - Piezoceramic (PZT-5H)
  - Piezo Film (PVDF)
  - Electrostrictor (PMN)
  - Magnetostrictor (TERFENOL)
  - Shape Memory Alloy (NITINOL)
  - Shape Memory Ceramics (PLZST)
  - Piezo Composites (0-3, 1-3, 2-2 Composites)
  - Fiber Optics
  - Electrorheological (ER) Fluids/Materials
  - Magnetorheological (MR) Fluids/Materials
  - Micro-Electro Mechanical Systems (MEMS)



## COMPARISON OF ACTUATION MATERIALS

	PZT-5H	PVDF	PMN	TERFENOL DZ	NITINOL	PLZST
Actuation Mechanism	piezoceramic	piezo film	electrostrictor	magneto-strictor	shape alloy	shape memory ceramic
$\epsilon_{\max}$ (strain)	0.13%	0.07%	0.1%	0.2%	2%-8%	0.3%-0.9%
E (Msi)	17	0.3	17	7	4 (m), 13 (a)	12 (FE)
$\sigma_{\max}$ (kpsi)	22.1	0.21	17	14	26-104	36-108
Density (kg/m <sup>3</sup> )	7500	1780	7800	9250	7100	7500
Actuation Energy	13.2	0.285	7.51	10.4	252-4032	49.6-446
Density (J/kg)	10%	>10%	<1%	2%	High	High
Hysteresis	-20C to 200C	Low	0C to 40C	High	<5Hz	0C to 40C
Temp Range	100kHz	100kHz	100kHz	<10kHz		<100Hz
Bandwidth						

(m) = martensite (a) = austenit (FE) ferroelectric

Actuation Energy Density =  $1/2 \epsilon_{\max} \sigma_{\max} / \rho$

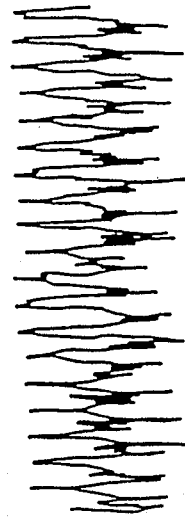
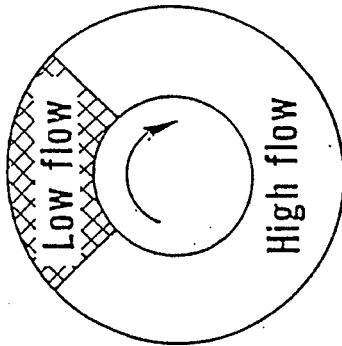
Source: Jacot, et al., Boeing

active95-14



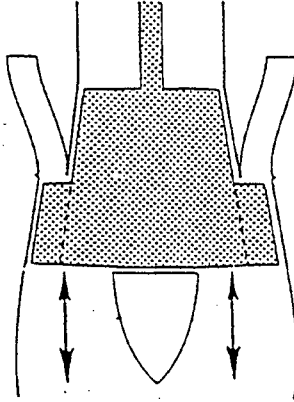
## COMPRESSOR FLOW INSTABILITIES

Rotating stall  
Circumferentially nonuniform flow



Frequency  $\sim 50 - 100$  Hz

Surge  
Axially oscillating flow



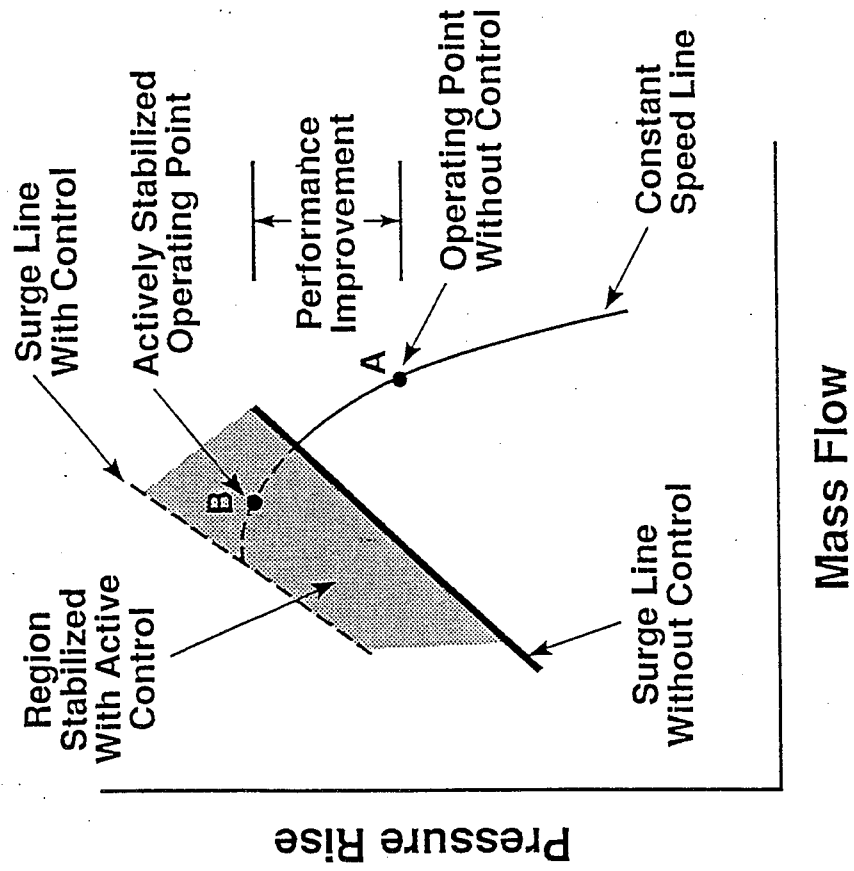
Frequency  $\sim 3 - 10$  Hz

Source: Epstein, et al., MIT

nasa3



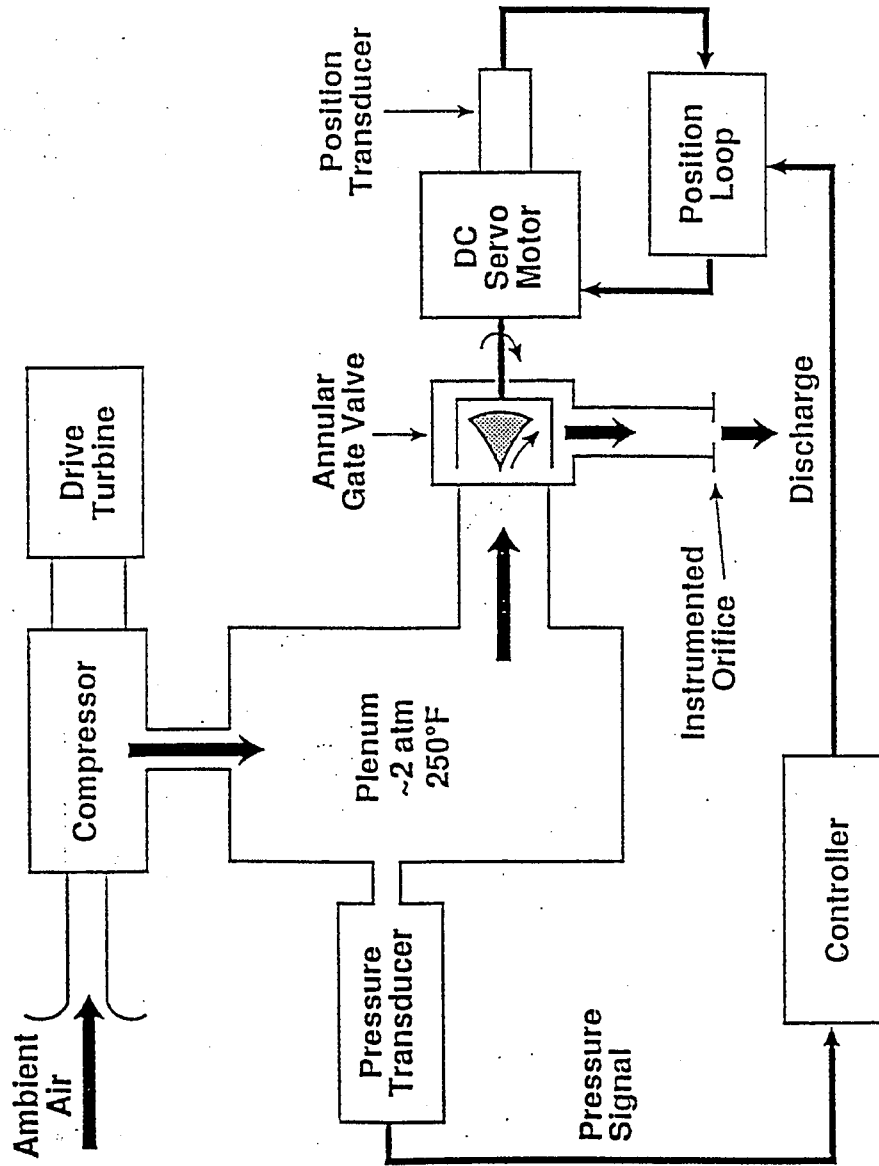
## ACTIVE COMPRESSOR STABILIZATION



Source: Epstein, et al., MIT

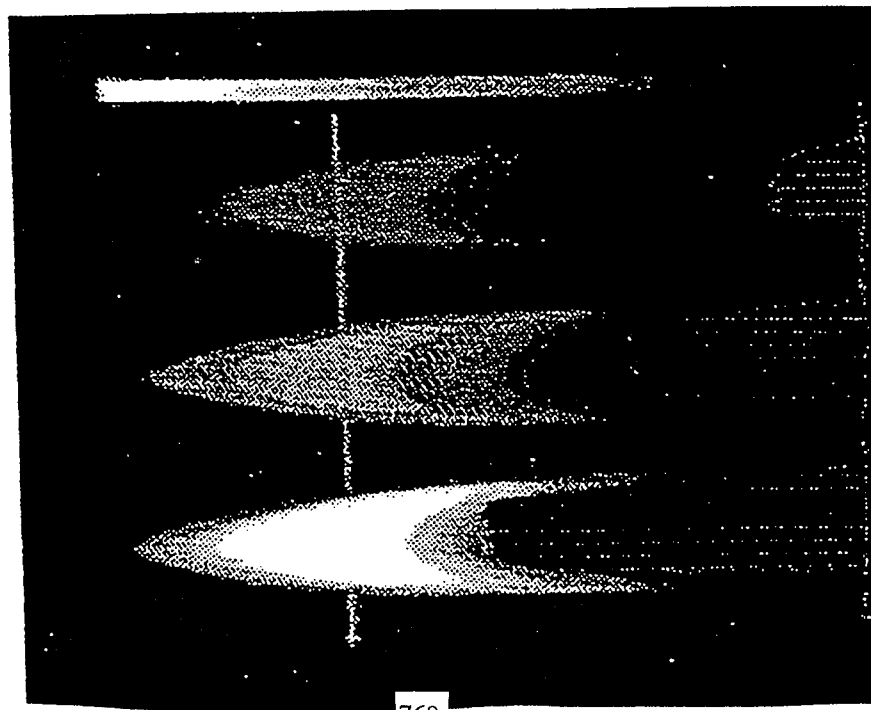


## ACTIVE CONTROL OF COMPRESSOR





## VISION-GUIDED FLAME CONTROL



controller

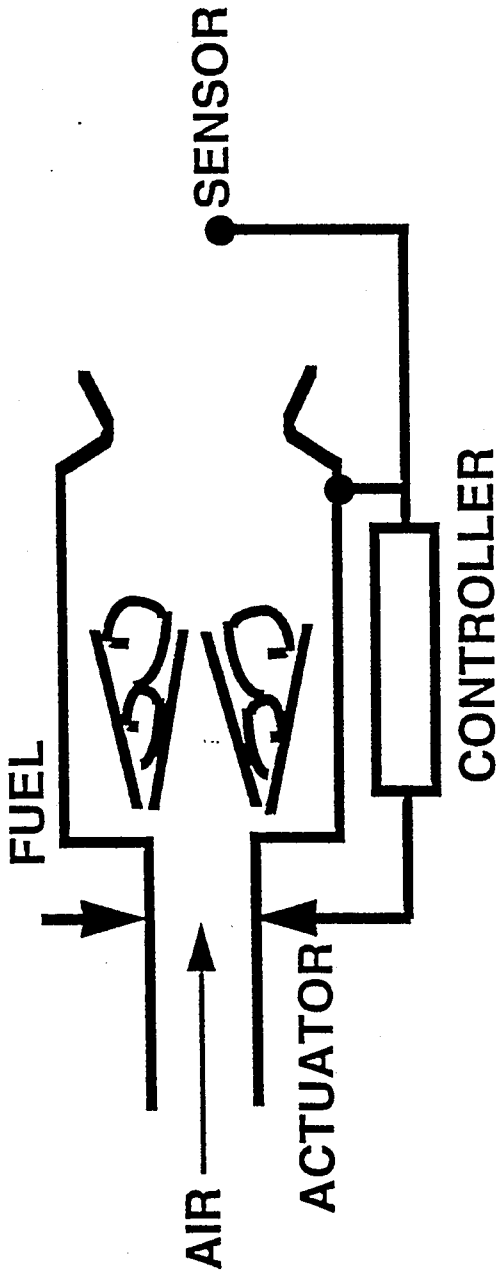
camera

oxygen

combustible

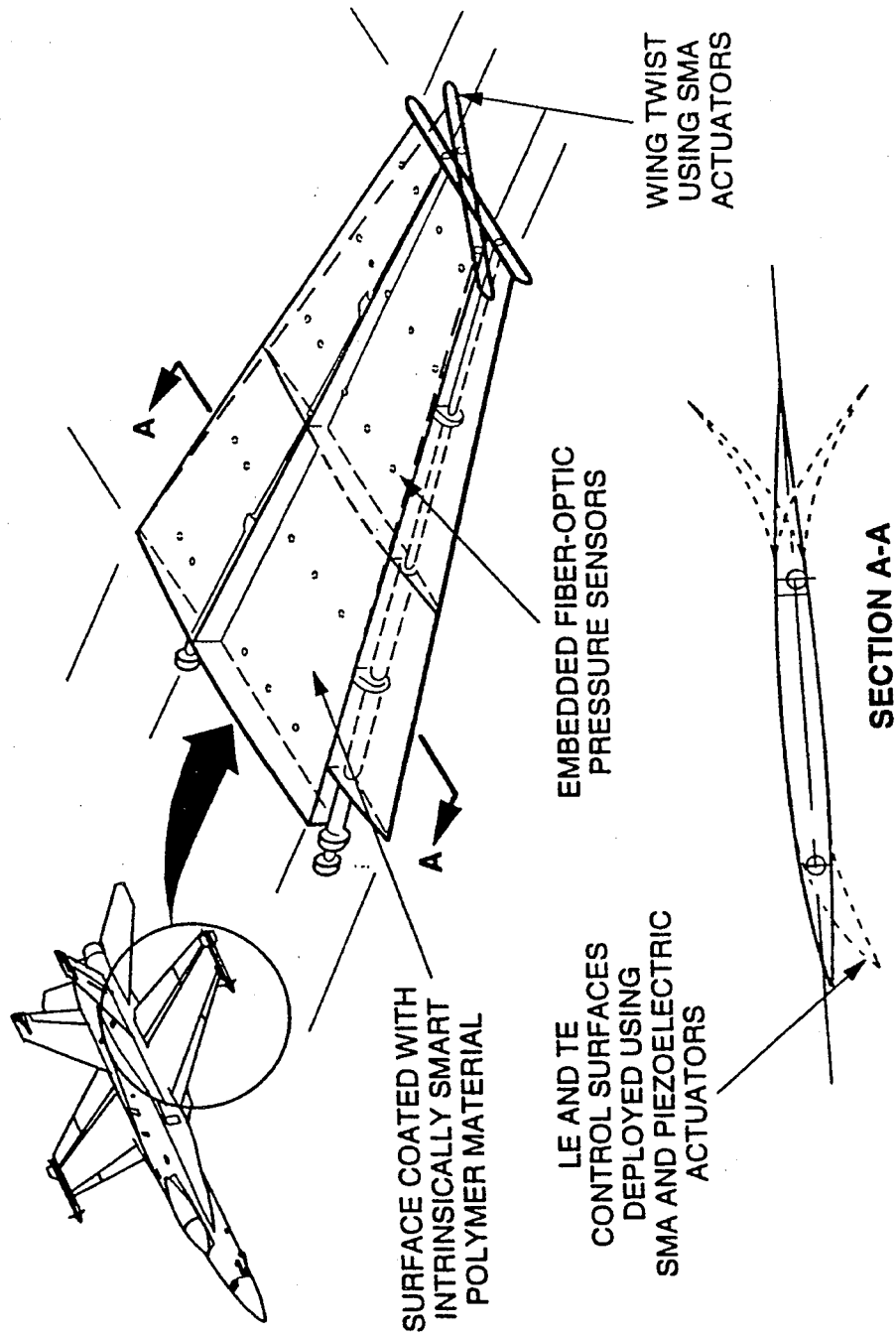


## CONTROL OF COMBUSTION PROCESS





## AIRCRAFT ADAPTIVE WING DESIGN (AIR FOIL SHAPE CONTROL)



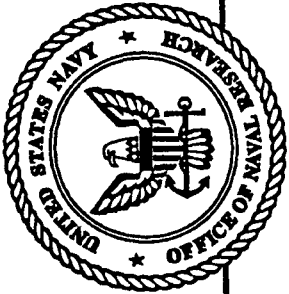
Source: Kudva et al., Northrop



## TECHNICAL ISSUES

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- **Control of:**
  - Random Noise
  - Stochastic Processes
  - Broadband Signals
  - Transients
- **Fault Identification & System Reconfiguration**
- **Control of Nonlinear Processes & Dynamics**
  - Power Electronic Systems
  - Both High & Low-Level Control of Vehicles
  - Chaotic Oscillations in Shipboard Crane



## RECOMMENDATIONS & FUTURE DIRECTIONS

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- Machinery Diagnostics and Prognostics is an *Enabling Technology* for effective maintenance
- Need for real-time and on-line capability
- Need a better understanding of failure mechanisms & physics-based models
- Reduce maintenance system cost - innovative sensors, signal extraction & data fusion techniques
- Provide reliable information & effective man-machine interface



## RECOMMENDATIONS & FUTURE DIRECTIONS

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- Active Control is an *Enabling Technology*
- Requirements & Criteria for Future Active Systems
  - Improve **Performance**
  - Reduce ***Cost***
  - Reduce **Complexity**
- Unified Control Methodology
  - High & Low-Level Controls
- Active/Passive Hybrid Control

